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ANALYSIS OF DIGITAL CELLULAR STANDARDS

by

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Cellular communications has become one of the fastest growing segments in the telecommunications industry. The demand for cellular services has risen beyond all expectations. With the current growth of the analog cellular network, a strain has been put on the existing system and available spectrum. Cellular providers have been forced to use the existing bandwidth more efficiently by converting to digital technology. Four major digital cellular techniques are competing for marketplace dominance and each has the ability to expand the capacity of the cellular networks. The four systems are Global System for Mobile Communications (GSM), the Pan-European standard that utilizes FDMA/TDMA, using 25 MHz bandwidth channels, and operates in the radio frequency bands of 890-915 MHz for the uplink and 935-960 in the downlink; Digital Advanced Mobile Phone System (D-AMPS), the North American Digital Standard which is backwards compatible with the existing AMPS system; IS-95 manufactured by Qualcomm Inc. which utilizes the newest of the technologies CDMA, and finally Personal Digital Cellular (PDC), Japan's alternative which also uses TDMA technology. It is uncertain which system will become the standard, but it is certain that the ability to get to the marketplace, dominate it, and secure a stronghold in the market will be the successful standard.

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ANALYSIS OF DIGITAL CELLULAR STANDARDS

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ABSTRACT

Cellular communications has become one of the fastest growing segments in the telecommunications industry. The demand for cellular services has risen beyond all expectations. With the current growth of the analog cellular network, a strain has been put on the existing system and available spectrum. Cellular providers have been forced to use the existing bandwidth more efficiently by converting to digital technology. Four major digital cellular techniques are competing for marketplace dominance and each has the ability to expand the capacity of the cellular networks. The four systems are Global System for Mobile Communications (GSM), the Pan-European standard that utilizes FDMA/TDMA, using 25 MHz bandwidth channels, and operates in the radio frequency bands of 890-915 MHz for the uplink and 935-960 in the downlink; Digital Advanced Mobile Phone System (D-AMPS), the North American Digital Standard which is backwards compatible with the existing AMPS system; IS-95 manufactured by Qualcomm Inc. which utilizes the newest of the technologies CDMA, and finally Personal Digital Cellular (PDC), Japan's alternative which also uses TDMA technology. It is uncertain which system will become the standard, but it is certain that the ability to get to the marketplace, dominate it, and secure a stronghold in the market will be the successful standard.

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LIST OF ACRONYMS

Acronym	Term
AMPS	Advanced Mobile Phone System
AuC	Authentication Center
bps	bits per second
BSC	Base Station Controller
BSD	Base Station Demodulator
BSS	Base Station Subsystem
BSM	Base Station Modulator
BTS	Base Transceiver Station
CAI	Common Air Interface
CDMA	Code Division Multiple Access
CDPD	Cellular Digital Packet Data
CEPT	Conference of European Post and Telecommunications
CMS	Cellular Mobile System
D-AMPS	Digital Advanced Mobile Phone System
DCS	Digital Communication Services
DQPSK	Differential Quadrature Phase Shift Keying
DTC	Digital Traffic Control
DSSS	Direct Sequence Spread Spectrum
EIA	Electronic Industries Association

EIR	Equipment Identity Register
ESN	Electronic Serial Number
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FDD	Frequency Division Duplexing
FDM	Frequency Division Modulation
FEC	Forward Error Correction
FDMA	Frequency Division Multiple Access
FH	Frequency Hopping
FM	Frequency Modulation
FPLMTS	Future Public Land Mobile Telecommunications System
FVC	Forward Voice Channel
Ghz	Gigahertz (10^9 x Hertz)
GMSK	Gaussian Minimum Shift Keying
GSM	Global System for Mobile Communications
HLR	Home Location Register
IN	Intelligent Network
ISDN	Integrated Services Digital Network
IS-54	Interim Standard 54 (Dual-Mode)
IS-95	Interim Standard 95 (CDMA)
JDC	Japanese Digital Cellular

kbps	kilobits per second (1,000 bits per second)
Khz	Kilohertz (10^3 x Hertz)
Mhz	Megahertz (10^6 x Hertz)
MoU	Memorandum of Understanding
MSS	Mobile Satellite Service
MSC	Mobile Switching Center
MTSO	Mobile Telephone Switching Office
NMT	Nordic Mobile Telephone System
PCS	Personal Communication Services
PDC	Personal Digital Cellular
PCN	Personal Communication Network
PLMN	Public Land Mobile Network
PSTN	Public Switched Telephone Network
RF	Radio Frequency
RVC	Reverse Voice Channel
SIM	Subscriber Identity Module
SMS	Short Messaging Service
SSD	Secret Shared Data
SVD	Serial Viterbi Decoder
TIA	Telecommunications Industry Association
TDMA	Time Division Multiple Access
TACS	Total Access Communications System

UMTS	Universal Mobile Telecommunication System
VLR	Visitor Location Register
VPM	Voice Privacy Mask
VSLEP	Vector Sum Excited Linear Prediction (speech encoding)

EXECUTIVE SUMMARY

Cellular communications has become one of the fastest growing segments in the telecommunications industry. The demand for cellular services has risen beyond all expectations. With the current growth of the analog network, a strain has been put on the existing system and available spectrum. Cellular providers have been forced to use the existing bandwidth more efficiently by converting to digital technology. Four major cellular techniques are competing for marketplace dominance and each has the ability to expand the capacity of the cellular networks.

The emergence of digital cellular introduces the idea of market competition among the four major digital standards: 1) Global System for Mobile Communications, 2) Digital Advanced Mobile Phone System, 3) Interim Standard-95, and 4) Personal Digital Cellular (PDC).

Global System for Mobile Communications (GSM) is the cellular communications standard developed by a special working group formed by the Conference of European Post and Telecommunications (CEPT). Initially known as Groupe Speciale Mobile, GSM was established as a solution to the rapid growth of the analog cellular telephone system and to establish an integrated European system. Growth of GSM has been strong in the European countries over the past year. It has experienced a growth rate that has been phenomenal, and it is believed that worldwide cellular subscribers will reach 100 million users. It is estimated that GSM will account for 82 percent of the world's 4.4 million digital subscribers.

Digital Advanced Mobile Phone System (D-AMPS), also known as the IS-54 Digital Cellular Standard, is the United States' standard developed in the late 1980s by the Cellular Telecommunications Industry (CTIA). The CTIA developed this standard as a solution to meet the growing need of increased cellular capacity in high density areas and to remain a cost-effective system by utilizing the existing

hardware and the spectrum of the existing Advanced Mobile Phone System (AMPS).

The first North American digital interim standard IS-54 was adopted in the United States, and the system was based on TDMA as the common air interface. Soon thereafter in 1990, the second interim standard appeared on the market developed by Qualcomm Inc. of San Diego. The proposed system uses a spread spectrum technique based on Code Division Multiple Access (CDMA). Originally designed for the military to prevent signals from being jammed or intercepted by hostile encounters, it was thought an inefficient use of the spectrum. However, spread-spectrum is a well established technology that only recently has been applied to the digital cellular market.

Personal Digital Cellular (PDC), also known as the Japanese Digital Cellular (JDC), was Japan's digital mobile communication system solution whose specifications were defined by Japan's Research and Development Center for Radio Systems (RCR). It is a TDMA-based system that operates in the 800 MHz and 1.5 GHz radio frequency bands, and therefore is similar to the American TDMA network with the only exception being that it was not designed to operate in the dual mode.

The general consensus of the market appears to be that one standard will not prevail. The prevailing standards appear to be GSM and CDMA. GSM is the more established technology of the two, and its successes have spread beyond Europe with operational networks worldwide. CDMA is the forefront of technology in digital cellular and the newest. It will be able to provide superior solutions for the wide spectrum of cellular communications and will become a major market contender once it has gone commercial.

All standards will have a place on the market because in one way or another, they have already been committed. Commitments like that will allow

standards like D-AMPS and PDC to remain alive on the market leader despite their incompatibilities with other standards on the market. The standard or standards that have the best chance of remaining a market leader will have the greatest probability of being implemented into third generation systems. All standards, regardless if they become the international standard, will have a niche in the market because of the backing and support the company has obtained. It is the responsibility of the market to sort it out and move toward the standards that offer the most advantages.

I. INTRODUCTION

A. PURPOSE OF THESIS

The purpose of this thesis is to explore the driving forces and limiting factors using market projections to determine which, if any, of the current digital cellular communication standards will dominate the marketplace.

B. DISCUSSION

Cellular communication has become one of the fastest growing segments in the telecommunications industry. Over the past five years, the demand for cellular services has risen above all expectations. By the year 2000, it is estimated that more than one million Americans will subscribe to cellular services. At the projected rate of growth, the analog communications industry will be unable to handle the increased user requirements. This growth spurt has put a strain on the available spectrum, and cellular companies are pressuring the regulatory bodies to allocate more bandwidth. In the meantime, cellular providers are forced to use the existing bandwidth more efficiently by converting from analog to digital technology.

Compared to analog, digital will increase the number of users by applying compression techniques that will expand the capacity of the cellular networks. Currently, there are four major cellular standards competing for marketplace dominance: 1) Global System for Mobile Communications (GSM), the pan-European digital standard which utilizes FDMA/TDMA technology and operates in the radio frequency band of 890-915 MHz for the uplink and 935-960 in the downlink; 2) Digital Advanced Mobile Phone System (D-AMPS) the North American digital standard that is backward compatible with the already existing AMPS (analog) system; 3) IS-95 manufactured by Qualcomm Inc. using Code Division Multiple Access (CDMA) which incorporates a spread spectrum

technique to spread signals across a wide frequency band; and 4) Personal Digital Cellular (PDC) or Japanese Digital Cellular (JDC), the Japanese digital standard that also uses TDMA as its multiple access technique.

Most of the major cellular carriers are beginning to align themselves with one or sometimes two of the major digital techniques. It is uncertain which technology will become the standard, but the decision relies on not only the advantages of the system but also the cellular market. Technology is not the main selling point; economics, competition, marketing and growth are just as important. Success of a digital standard will not be determined just by its sophistication but by the ability of its providers to get to the marketplace, dominate it, and secure a stronghold in subscriber growth.

C. SCOPE

This thesis will focus on the four major digital standards available in the marketplace and determine which standard will dominate. The assumptions and conclusions made in this thesis are strictly for discussion. Due to the rapid changes in the cellular field, some of the source materials may change and become outdated as further testing and evaluation of the standards occur.

D. THESIS ORGANIZATION

Chapter I provides an introduction and a basic foundation for the scope of this thesis. Chapters II through V provide general overviews of each of the four standards with basic background as to the origin of the system, analysis and basic operation, advantages and disadvantages of each, and a market outlook as to the survivability of the system in the future. Finally, Chapter VI will explore the two leading systems and compare trends in economic growth, technology, and competition.

II. GLOBAL SYSTEMS FOR MOBILE COMMUNICATIONS (GSM)

A. BACKGROUND

The Global System for Mobile Communications (GSM) is a cellular communications standard developed by a special working group formed by the Conference of European Post and Telecommunications (CEPT). Initially known as Groupe Speciale Mobile, GSM was established as a solution to the rapid growth of the analog cellular telephone system and to establish an integrated European system. In 1987, a significant step in the development of GSM occurred with the signing of the Memorandum of Understanding (MoU) where 18 countries committed themselves to implementing the standard based on GSM. The MoU committee was tasked to design a digital standard that would provide greater capacity, security, and allow international roaming between the world's GSM network. In 1989 the responsibility was shifted to the European Telecommunication Standards Institute (ETSI) with plans to have the service installed in 1991. The proposed system had to meet the following criteria [Scourias, 1995, p. 2]:

- Integration of voice and data
- Improved voice quality and handover
- Low terminal and service cost
- Pan-European roaming
- Secure transmissions
- Ability to support hand-held terminals
- Support for range of new services and facilities
- Increased spectral efficiency
- ISDN compatibility.

GSM was initially planned to be implemented in three phases: Phase 1, Phase 2, and Phase 3 [Titan Corporation, 1995, p. TECH 7].

- Phase 1, implemented in 1992, provided initial GSM capability and is the currently deployed system. It provides basic voice services and a few supplementary services such as emergency calling features as outlined in Table 1 [Redl, Weber, 1995, pp. 23-25].

Table 1. List of GSM Phase 1 Services

Service Category	*Service*	*Comment*
Teleservices	Telephony (speech)	So-called full rate, 13 kbps
	Emergency calls (speech)	
	Short-message services; point - to point and point-to multipoint (cell broadcast)	Alphanumeric information; user-to-user and network to all users
	Telefax	Group 3
Bearer Services	Asynchronous data	300-9600 bps, 1200/75 bps
	Synchronous data	300-9600 bps
	Asynchronous PAD (packet-switched, packet assembler/ dissembler) access	300-9600 bps
	Alternate speech and data	300-9600 bps
Supplementary Services	Call forwarding	For example, subscriber busy, not reachable or does not answer
	Call barring	For example, all calls, international calls, incoming calls

- Phase 2 whose specifications were frozen in 1992, introduced a large range of additional features to include call waiting, caller information services and improvements in the subscriber identity module (SIM) cards, which contained caller identification as further outlined in Table 2 [Redl, Weber, 1995, p. 25].
- Phase 3 was scheduled to be implemented in 1996 and it will be an improvement upon the already established Phase 2. To date, the Phase 3 services are not published, but it is assumed they will continue to correct the weaknesses based on the lessons learned in Phase 2 [Salinger, 1994, p. 2].

To date, 36 countries have committed to GSM and 25 other countries are considering as shown in Table 3. There are two main reasons why many of the

countries are considering GSM. First, is it is an evolving technology. GSM has evolved from a voice-only service to a system that offers a wide range of services. It is predicted that GSM will have the capability to provide higher data rates, support multimedia, and support video conferencing. Secondly, it is based on an open standard. This open standard provides a strong market involvement and greatly accelerates product development, price reduction, and new product growth to create a competitive global market for the GSM infrastructure.

Table 2. List of Services Added Through GSM Phase 2

Service Category	*Service*	*Comment*
Teleservices	Telephony (speech)	Half rate, 6.5 kbps
	Short-message services	General Improvements
Bearer Services	Synchronous dedicated packed data access	2400-9600 bps
Supplementary Services	Calling/connected line identity	Restricts the display of the calling party's number before/after call connection
	Call waiting	Informs user about a second (incoming) call and allows to answer it
	Call hold	Puts an active call on hold in order to answer or originate another (second) call
	Multiparty communication	Conference calls
	Closed user group	Establishment of groups with limited access
	Advice of charge	Online charge information
	Unstructured supplementary services data	Offers an open communications link for use between network and user for operator-defined services
	Operator-determined barring	Restriction of different services, call types by the operator.

Table 3. Countries Currently Committed to GSM

COUNTRY	OPERATOR	YEAR
Australia	TELECOM Australia (Telstra)	1992 (A)
	Optus	1992 (A)
	Vodafone	1993 (A)
Austria	Austrian PTT	1993 (O)
Bahrain	Batelco	1994 (A)
Belgium	RTT Belgacom	1993 (O)
Cameroon	Ministry of Posts & Telephones	1992 (A)
China	Jiaxing P&T	1993 (A)
	Shanghai P&T	1993 (A)
Denmark	Tele Danmark Mobil	1992 (O)
	Dansk Mobiltelafon	1992 (O)
Egypt	ARENTO	1994 (A)
Estonia	Telecom Finland	1994 (O)
Fiji	Fiji Posts & Telecom, Ltd.	1993 (A)
Finland	Telecom Finland	1991 (O)
	Radiolinja	1991 (O)
France	France Telecom	1992 (O)
	Cofira SFR	1992 (O)
Germany	Deutsche Bundespost Telekom	1993 (O)
	Mannesmann Mobilfunk	1992 (O)
Greece	2 operators	1993-4 (O)
Hong Kong	CSL	1992 (O)
	SmarTone	1992 (A)
	Hutchison	1993 (A)
Hungary	Westel 900	1993 (A)
	Pannon	1993 (A)
India	8 operators (different regions)	1993 (A)
Indonesia	PT TELEKOM	1993 (A)
	Satelindo	1993 (A)
Iran	Telecommunications Iran	1993 (A)
Ireland	Telecom Ireland	1992 (O)
Italy	SIP Italy	1992 (O)
	2nd operator	1993 (L)
Kuwait	MTSC	1994 (A)
Luxembourg	P & T Luxembourg	1992 (O)
Malaysia	Binarlang Sdn. Bhd.	1994 (A)
Netherlands	PTT telecom	1992 (O)
New Zealand	Bell South	1992 (A)
Norway	Norwegian Telecom Tele-Mobil	1992 (O)
	Netcom GSM A/S	1993 (O)
Philippines	Globe Telecom	1993 (L)
	Ista Communications	1993 (L)
Pakistan	PMCL	1993 (A)
Portugal	Telecel	1992 (O)
	TMN	1992 (O)
Qatar	Q-Tel	1993 (A)
Russia	26 operators (different regions)	1993-4 (L)
Saudi Arabia	1 operator	1994 (T)
Singapore	Singapore Telecommunications	1992 (A)
South Africa	Vodacom	1993 (A)
Spain	Telefonica Spain	1992 (O)
Sweden	Swedish Telecom	1992 (O)
	Comvik GSM AB	1992 (O)
	AB Nordic Tel	1992 (O)
Switzerland	Swiss PT Telecom	1992 (O)
Taiwan	Shinawatra	1994 (A)
Turkey	Turkcell	1993 (A)
	Telsim Mobil	1993 (A)
U. A. E.	Etisalat	1993 (A)
U. K.	Vodafone	1991 (O)
	Cellnet	1993 (O)
Vietnam	DGPT	1993 (A)

(A) = Contracts Awarded (L) = License Granted (O) = Operational (T) = Tenders Offered

* Other countries with announced plans to build GSM networks include:
Belarus, Bulgaria, Czech Republic, Jordan, Latvia, Lebanon, Morocco, Oman, Poland, Romania, Tunisia, Ukraine

Source: [Salinger, 1994, p. 4].

Currently, growth has been strong in the European countries over the past year. It has experienced a growth rate of approximately 280 percent in the past year as opposed to analog's 80 percent. GSM now accounts for about 35 percent of the total cellular market in eastern Europe. It is believed that worldwide cellular subscribers will reach 100 million users over the next few years, and it is estimated GSM will account for 82 percent of the world's 4.4 million digital subscribers [Titan Corporation, 1995, p. EUR-3].

B. ANALYSIS OF THE SYSTEM

The GSM network can be divided into three main network segments: the Mobile Station (MS) which is carried by the subscriber, the Base Station Subsystem (BSS) which controls the radio link with the Mobile Station, and the Network Subsystem, the main part which is the Mobile Services Switching Center (MSC) which is responsible for the switching of calls between the mobile and other fixed or mobile network users. See Figure 1.

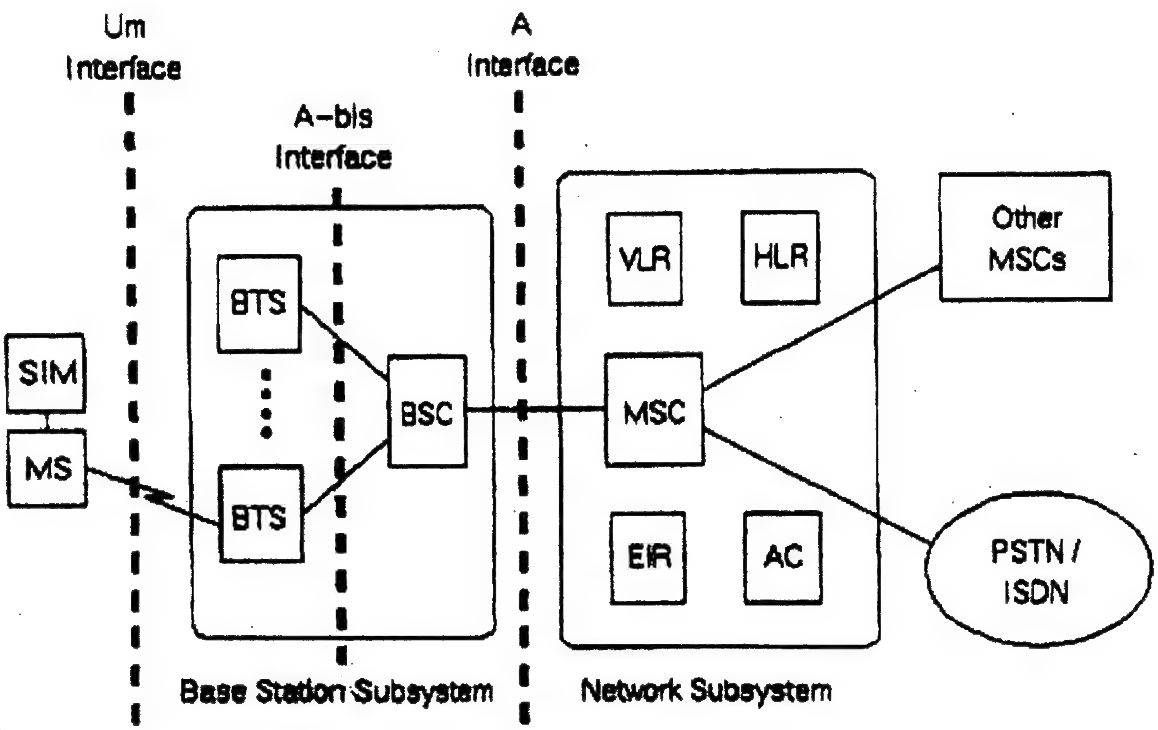

Figure 1. GSM Architecture

Source: [Scourias, 1995, p. 4].

1. Mobile Station (MS)

The mobile station (MS) consists of two parts: the mobile equipment (ME) and a smart card called the Subscriber Identity Module (SIM). The Mobile Equipment consists of five approved power classes. Their power levels are 20, 8,

5, 2, and 0.8 Watts. These correspond respectively to 43, 39, 37, 33, and 29 dBm. The 20 and 0.8 W units are designed for vehicular use and the 2 and 8 W are designed for hand-held use. There are also intermediate-sized portable units of 8 and 5 W power [Salinger, 1994, p. 17]. The SIM card is about the size of a credit card, and it allows a particular user to access the subscriber service regardless of the terminal being used. It identifies the subscriber's account to the network. The network will deny any access to the subscriber if the account is outstanding or the SIM card has been reported stolen. By inserting the SIM card into another terminal, the subscriber is able to receive and make calls at another terminal. The SIM card is protected from unauthorized use by a Personal Identity Number (PIN), which the subscriber chooses. Once the SIM card is removed from the mobile station, the ME will no longer function. Calls cannot be placed or received unless it is an emergency call (but only on some GSM networks).

2. Base Station Subsystem (BSS)

The Base Station Subsystem (BSS) connects the mobile station and the network switching substation. The BSS consists of two parts: the Base Transceiver Station (BTS) and the Base Station Controller (BSC). The Base Transceiver contains the radio transceivers and signaling equipment to interact with the mobile station and it is located at the cell site. The BTS is not an intelligent component, and it is maintained by the BSC. The Base Station Controller is tasked with the switching function of managing the radio resources for one or more BTSs in the Base Station System. The purpose of the BSC is to allocate radio channels and handovers, as described below in placing a GSM call.

3. Mobile Switching Center (MSC)

The Mobile Switching Center is the interface between the base station system and the switching subsystem. The system is also the interface between the PSTN or ISDN (Integrated Services Integrated Network) in the cellular network.

The GSM network design is similar to the switching system of a conventional telephone exchange. It must ensure all the calls are routed to subscribers no matter where they are located. Each designated area is allotted an MSC, and it is responsible to its subscribers within its service area. The MSC has to control and coordinate the handoff activities and manage all its radio resources which will be explained later in the paper.

4. Station Location

The mobile station's location can be maintained by a two-level hierarchical strategy with four types of data bases: the Home Location Register (HLR), the Visitor Location Register (VLR), the Authentication Center (AuC), and the Equipment Identity Register (EIR).

a. Home Location Register (HLR)

The Home Location Register (HLR) provides the call-routing and roaming capabilities of GSM. It is the central data base where all subscriber information and current location of the mobile station is maintained. There is usually one HRL per GSM network.

b. Visitor Location Register (VLR)

The Visitor Location Register (VLR) is a data base connected to a MSC which allows any mobile station in the MSC area to make and receive calls. The mobile station's identity and the area the subscriber was last registered is included. Any supplementary services the subscriber uses will also be included. The MSC will inform the VLR every time a mobile station attempts to place a call and verify the request before proceeding.

c. Authentication Center (AuC)

The Authentication Center (AuC) is used for security management, the authentication of subscribers, and encryption over the radio channels. It is used to validate the SIM card used by a particular mobile station. The

authenticating data is held in both the AuC and the SIM card. If the data conforms, authentication is complete.

d. The Equipment Identity Register (EIR)

Another aspect of security and registration is the Equipment Identity Register (EIR). This data base contains listings of all the authorized mobile equipment on the network. Each piece of equipment is identified by its International Mobile Equipment Identity (IMEI), and if it is recorded as invalid or stolen, it will not be approved.

5. Call Handling

Placing a call on the GSM system is comparable to placing a call on any other network. Calls can be placed from one MS to another MS or from the PSTN to a MS or vice versa.

a. MS-to-MS

Placing a call from one MS to another MS is the most basic GSM call operation as shown in Figure 2. The call begins with the call originating from one MS by requesting a call connection for an assignment to a channel. Once the request is sent through, an access control request is sent to the VLR. If the VLR does not acknowledge the request, the MS has to go through an identification request so the VLR can recognize the MS/SIM. After the MS is authenticated, the VLR will acknowledge the request with an acknowledgment message sent back to the MSC. An encryption procedure is utilized to change to the encrypted mode of transmission on the radio frequency interface. At this point, the MS originating the call sends a setup message with the number being called and the originating number. Once the numbers are authorized for the desired services requested, the MSC will send out an acknowledgment for the call to be placed. The MSC will verify the MS-ISDN phone number of the called party to verify it has been

registered with the local HLR. Once verified, the MSC will query the VLR to setup for an incoming call [Salinger, 1995, p. 77].

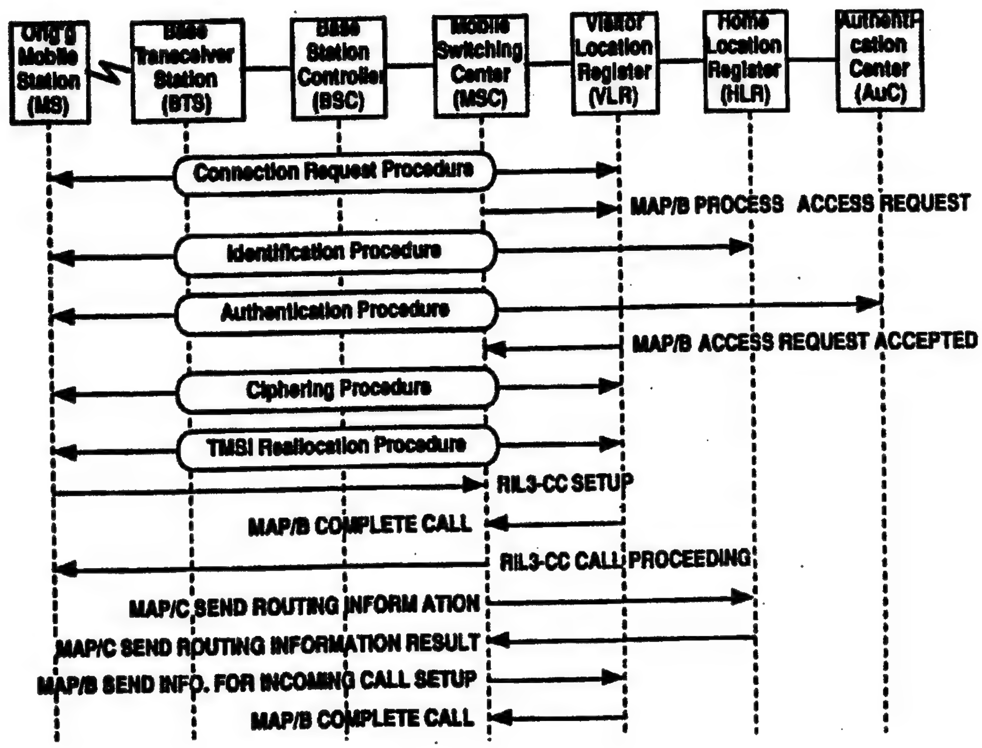

Figure 2. Placing a Call From One MS to Another MS

b. MS to PSTN or ISDN

Another way calls can originate with GSM is from the MS to the PSTN/ISDN or vice versa. The MS originating the call will get through the same procedures as the MS in an MS-to-MS call as shown in Figure 3. From here, the MS will transmit a message with its MS-ISDN number and the phone number of the land line phone it is trying to make a connection. Next, the MS is assigned a traffic channel. At the same time, the MSC starts to establish the connection with the called party by sending a message that contains the address, routing and

handling information, to the PSTN or ISDN switching center. The switching center relays this message and routes the call to the called party. When the called terminal receives the message, it rings to alert the called party and returns an address-complete message to the PSTN of ISDN switching center, which relays the message to the GSM MSC. The MSC will inform the MS that the called party has been alerted [Salinger, 1995, p. 80].

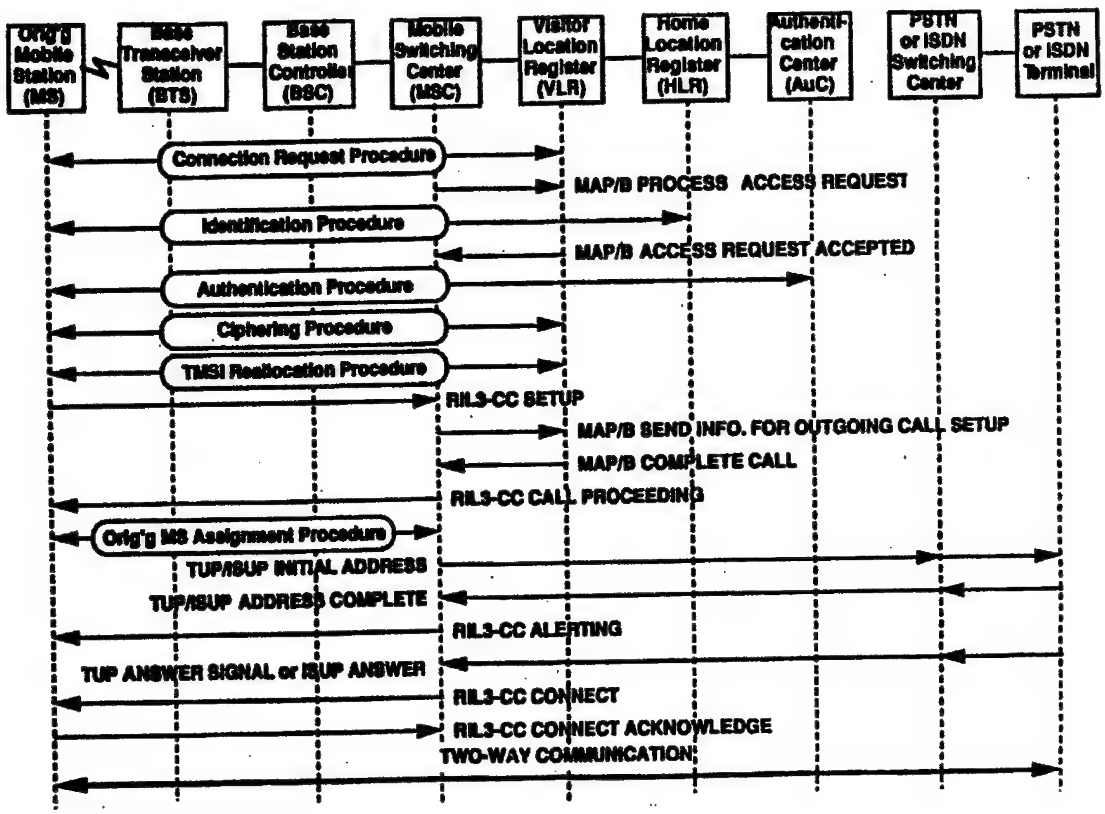

Figure 3. Placing a Call From MS to PSTN or ISDN

Hand-offs can occur in different situations. Cells sometimes become congested, and to reduce the workload, a hand-off may occur. Mobile stations continuously monitor the signal strength and report to the BSS. The BSS will measure the uplink to determine if a hand-off is needed.

Hand-offs can also occur when a new cell has been selected. There are three types. One is the intra-BSC hand-off where the new cell and the old cell are connected to the same BSC. Another is the inter-BSC hand-off where the old cell and new cell belong to different BSCs, and finally the third is an inter-MSC hand-off where the old cell and new cell belong to different MSCs.

6. Radio Channel

GSM uses a combination of Time Division Multiple Access and Frequency Division Multiple Access (TDMA/FDMA). The GSM standard specifies the frequency bands of 890 to 915 MHz for the uplink band and 935 to 960 MHz for the downlink band, each band divided into 200 kHz channels by means of 124 duplex radio channels. Each of those 200 kHz channels are further subdivided into eight time slots to incorporate the TDMA technique. Other features of the radio channel interface include adaptive time alignment, Gaussian Minimum Shift Keying (GMSK) modulation, discontinuous transmission and reception, and slow frequency hopping. Adaptive time alignment enables the MS to correct its transmit timeslot for propagation delay. GMSK modulation provides the spectral efficiency and low out-of-band interference required in the GSM system. Discontinuous transmission and reception refers to the MS powering down during idle periods and serves the dual purpose of reducing co-channel interference and extending the portable unit's battery life. Slow frequency hopping is an additional feature of the GSM radio channel interface which helps to counter the effects of Rayleigh fading and co-channel interference [GSM Security and Encryption, 1995, p. 3].

a. Frequency Division Multiple Access (FDMA)

FDMA is the least complicated technology among the different multiple access techniques. Analog communication systems typically use the FDMA methodology of frequency planning. With this method, the available

frequency bandwidth is split into numerous channels with bands between each channel to act as buffers to prevent channel interference between adjacent callers. See Figure 4. Each channel supports one telephone conversation at a time. Once the previous subscriber terminates the call, the channel becomes available to the next subscriber.

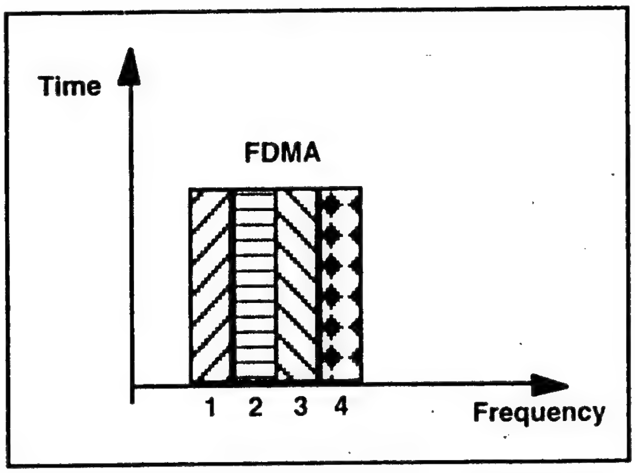

Figure 4. Frequency Division Multiple Access

Source: [Garg, Wilkes, 1996, p. 42].

FDM technology is mature and relatively simple to use, but unlike digital cellular the FDM technology does not take advantage of gaps in speech. By not using all of the available bandwidth, analog systems using the FDM technology do not have the flexibility for growth.

b. Time Division Multiple Access (TDMA)

The TDMA aspect of GSM divides the frequency channels into individual time slots. Eight time slots compose a frame of 4.6 ms. TDMA frames of 26 or 51 are grouped into multiframes (120 or 235 ms) depending on whether the channel is designated for traffic or control data. This TDMA scheme allows for a guard band as a buffer between the adjacent signals as shown in Figure 5. Each time slot is made available to different subscribers on a fixed schedule. This is an

advantageous situation because several subscribers can occupy a given frequency channel, one on each slot. Since many channels can be transmitted at once, the mobile station does not have to constantly transmit, and the transmitter power and RF spectrum are used more efficiently.

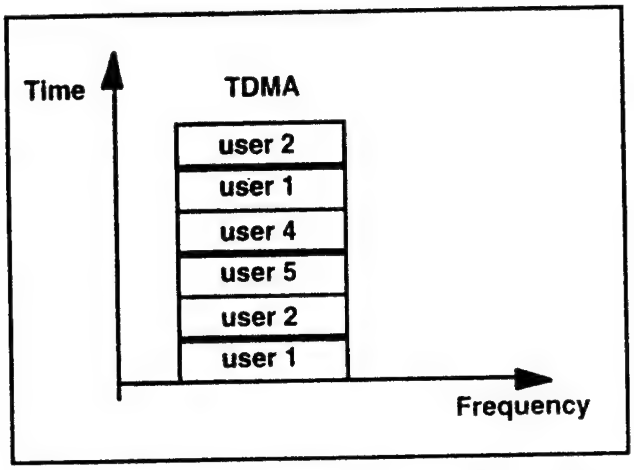

Figure 5. Time Division Multiple Access

Source: [Garg, Wilkes, 1996, p. 42]

A channel is defined by the number and position of its corresponding burst periods. A "burst" is defined as a frame which contains modulated data. There are five different types of bursts: normal, frequency correction, synchronization, dummy, and access bursts. See Figure 6. For the purpose of this paper, only the normal burst will be explained. The normal burst transmits speech or data to and from the MS user. It is composed of a 3-bit start sequence, 116 encrypted bits split into 2 groups of 58 bits, a 26-bit training sequence used to help counter the effects of multipath interference, a 3-bit stop sequence required by the channel coder, and a guard period (8.25 bit duration) which is a cushion to allow for different arrival times of bursts in adjacent timeslots of geographically dispersed MSs. At the beginning and end of each burst, there is a group of bits called tail bits. These tail bits are used to avoid a loss of demodulation efficiency

for the extreme information bits, and to provide a known initial and final state that reduces the Viterbi decoder error in finding the correct delay profile [Salinger, 1994, p. 56].

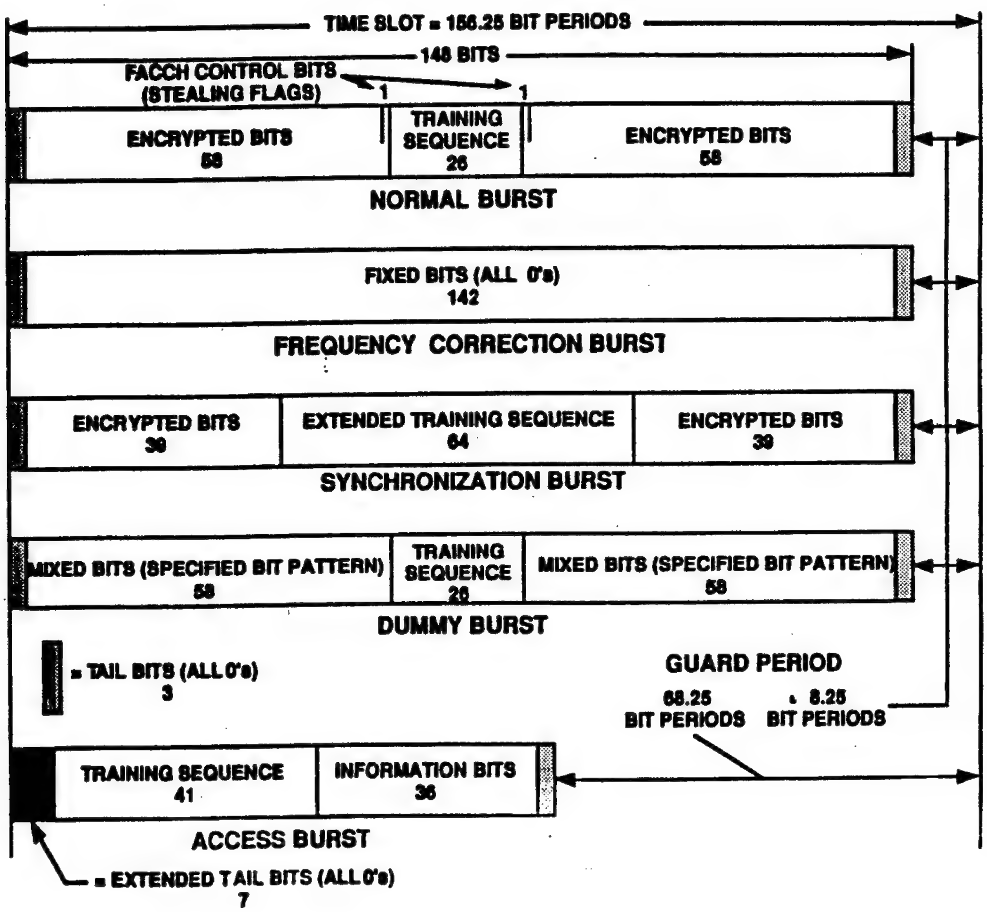

Figure 6. Time Slot Bursts

Source: [Salinger, 1994, p. 55].

c. *Interleaving*

Radio channel interference usually occurs in the mobile radio system at data rates much slower than the 270 Kbps transmission rate of GSM, where errors tend to occur in bursts. This may destroy an entire TDMA burst. To overcome this, the bits in each message block are interleaved over eight bursts,

which reduces the average error per block to a rate manageable by the forward error correction (FEC) [Salinger, 1994, p. 54].

Given a speech sample stream as shown in Figure 7, consisting of a 456-bit message block, it is arranged into a matrix of 57 rows of eight bits. The data is extracted by 57-bit columns into 8 x 57 bit strings. The data is then interleaved with adjacent speech sample streams. The overall effect is to stretch the speech over a longer time period to minimize the input of noise (burst) on the speech data. This technique is known as diagonal interleaving.

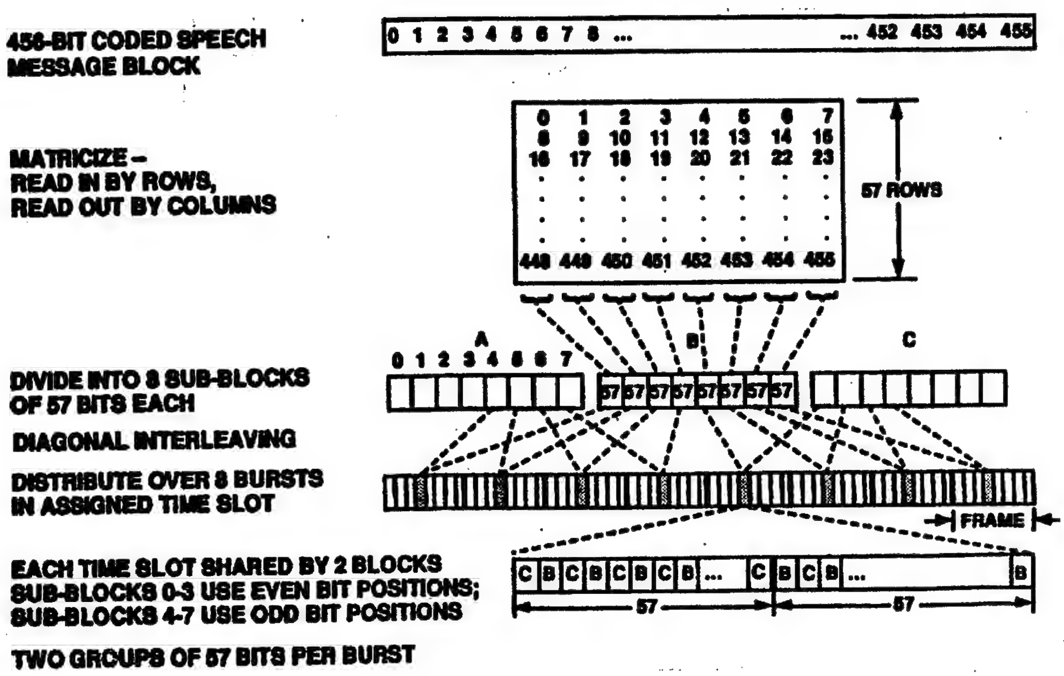

Figure 7. Interleaving

Source: [Salinger, 1994, p. 54].

C. ADVANTAGES AND DISADVANTAGES

1. Advantages

GSM will provide a number of additional advantages over the existing cellular system. Privacy will be accomplished with encryption and improved voice

quality, and the data services provided will be an essential part of the system. From an engineering aspect, other advantages will be higher network capacity and greater mobility.

a. Security

GSM provides greater digital security and encryption which reduces the possibility of fraud. Its security and authentication mechanisms make it the most secure cellular communication standard currently available. Even though the confidentiality of a cellular call can only be guaranteed on the radio channel, GSM is a major step towards secure communications.

b. Capacity

In addition to greater security, GSM will integrate voice and data as an additional benefit to attract more subscribers. Increased radio spectrum efficiency provides a greater network capacity. Since it is such a modular system, it allows the carriers to accommodate system growth very easily and to efficiently utilize the assigned frequency. GSM's digital encoding only uses 50 percent of the analog channel bandwidth, therefore the system operators can derive more channels from the same frequency band.

Another way GSM increases capacity is to put cells close together so frequencies can be used more often in a given area. The modulation system had to be designed to be highly resistant to co-channel modulation.

c. Services

GSM is available to subscribers with a list of services like voice communication, facsimile, voice mail, short message transmission, and supplemental services such as call forwarding.

d. Mobility

GSM's single standard allows international roaming to any location serviced by the network. The person making the call does not have to be aware of

the subscriber's locality because GSM does not locate users. With the SIM card, a user has the ability to be in touch globally. All that is needed is to place the card into any GSM terminal.

e. Interoperability

GSM is based on international standards that were defined by the European Telecommunications Standards Institute (ETSI). GSM has the ability to work with networks around the world as long as the equipment used conforms to ETSI standards.

2. Disadvantages

The major disadvantage of GSM is the data portion of the system is lingering behind the voice portion because of administrative cost. The operators of GSM have to install additional equipment to the system to be able to transmit data and faxes on the normal Public Switched Telephone Network [Gronert, 1995, p. 88].

Since GSM supports both voice and data, it must have the ability to transfer between the two. The requirements for the voice and data conflict. Voice can handle transmission gaps, but it is sensitive to traffic delay. Data can handle traffic delay, but not transmission gaps.

D. MARKETING OUTLOOK

The cellular market predicts that Global System for Mobile Communications will be the leading cellular standard for the future. As of 1995, both the TACS and GSM cellular networks have the highest subscriber rates throughout Europe with 8.4 million and 7.1 million respectively (74 percent of the market). By 1997, it is forecast that GSM subscribers will surpass the combined analog cellular users in Europe. If the trend continues into the year 2000, GSM is predicted to be the market leader with an estimated 210 million or 60 percent of the market share. [Titan, 1995, p. EUR-1] See Figure 8.

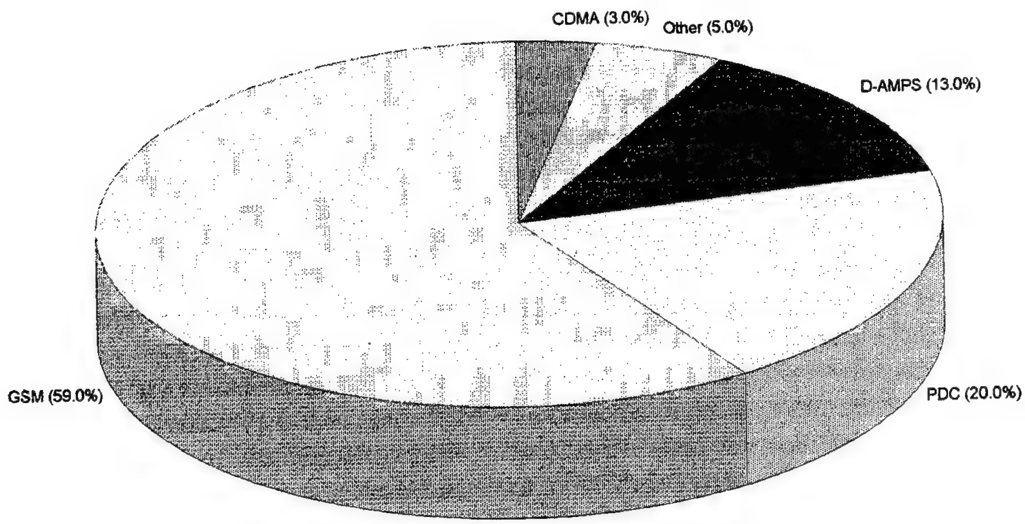

Figure 8. 1995 European Cellular Standard Market

Source: [Titan Corp., 1995, p. EUR-3].

1. Positive Aspects

When GSM came on the market, it was originally specified as the Pan-European digital cellular standard. There are approximately 70 operational networks in Europe, Asia and Latin America, and GSM is gaining strength in areas where American analog was digital standard. GSM has been established and operating for approximately three years and as of September 1995 had over 10 million subscribers. This system not only offers a higher capacity and bandwidth but also the ability to offer more elaborate networking options than the analog standards.

There is no single global standard today. It was hoped that GSM would replace the existing European analog cellular network and eventually take over the global market. By initiating this single open standard it would create market competition and drive the handset prices down. GSM would be ideal in establishing a good balance between the standards and the framework for vendors. It would still allow for manufacturers to differentiate their products and maintain

lower prices. GSM currently has the best open standard of all the digital techniques in the world.

The MoU chose TDMA as the multiple access technique for GSM. One of the factors in the acceptance of TDMA was, since its deployment, it has consistently tracked in the right direction with its two year head start over the other multiple access techniques. The real debate about which multiple access technique will be the digital standard is not whether one technique is better than the other, but whether or not the technology was on the market and available at the time of such a crucial decision.

GSM is looking to push into the American market with another form of GSM which operates in the 1900 MHz bandwidth known as PCS-1900. If this technology can be integrated into the U.S. market, this could only be a huge plus for GSM. GSM will be strengthened as a technology and will have a greater chance of breaking through the international market and being fully accepted. The North American market is known for its size and capacity for rapid growth which would make it a significant driving force for the acceptance of GSM as the global digital standard. If GSM could be accepted as the digital standard in the United States, this would significantly affect the market competition and accelerate the acceptance of GSM in other markets that are not supporting a digital standard.

2. Negative Aspects

The North American market could potentially be a positive driving force for GSM, but it could be a negative one also. Some of the strongest selling points of GSM in Europe could make it vulnerable in the United States. GSM offers many advanced services from a single network as outlined in Table 2. One is the ability to provide transparent, effortless and efficient roaming. This makes it very important for GSM to have an established network in the United States to be able

to provide the same roaming capability it can provide in Europe. There are many major markets that do not provide GSM services [Ericcsson, 1996, p. 53]:

- Chicago, IL
- Seattle, WA
- Denver, CO
- Cleveland, OH
- Louisville, KY
- Lincoln, NE
- Wichita, KS
- Little Rock, AR
- St. Louis, MO
- Minneapolis-St. Paul, MN
- Cincinnati, OH
- Richmond and Norfolk, VA
- Atlanta, GA
- New Orleans, LA
- and half a dozen others

If the United States does not accept GSM as a digital standard, the market could work against the technology and accept another technology as the standard. GSM and PCS 1900 might be accepted in the United States, but they may possibly have to co-exist with other digital platforms that are already in place. With these concerns surrounding GSM, there is still a chance GSM will prevail. Although technically behind some of the other competing standards on the market, it is still the world leader in standards.

III. DIGITAL ADVANCED MOBILE PHONE SYSTEM (D-AMPS)

A. BACKGROUND

The Digital Advanced Mobile Phone System (D-AMPS), also known as the IS-54 Digital Cellular Standard, is the United States' standard developed in the late 1980s by the Cellular Telecommunications Industry Association (CTIA). The CTIA developed this standard as a solution to meet the growing need of increased cellular capacity in high density areas and to remain a cost-effective system by utilizing the existing hardware and the spectrum of the existing Advanced Mobile Phone System (AMPS).

The AMPS network has the ability to migrate to digital by allocating a few radio channels for digital operation. As the subscriber rate for digital increases, the networks can convert more channels to digital operation, and the users that want dual functionality can convert to dual-mode phones.

AMPS was the first generation analog system developed by Bell Laboratories in the 1970s. It was the first true cellular system in the United States using Frequency Division Multiple Access (FDMA) operating in the 800 MHz radio frequency developed in the world. AMPS utilizes two frequency bands, 824-849 MHz for the mobile transmit and 869-894 MHz for the mobile receive. Since IS-54 is a dual-mode system, it has the ability to provide both analog and digital operation, to be able to maintain compatibility with the AMPS system.

B. ANALYSIS OF THE SYSTEM

With the incorporation of TDMA technology, each 30 kHz channel is split into three time slots thereby increasing capacity three-fold over AMPS. Analog voice channels remain the same with the exception of additional codes written to support handoff to digital traffic channels [Nguyen, 1995, p. 55].

A significant feature of IS-54 is the Digital Traffic Channel (DTC) which carries digital voice, data and control messages. Each DTC provides a raw RF bit rate of 48.6 Kbs, achieved using $\pi/4$ DQPSK (differential quadrature phase shift keying) at the 24.3 kHz channel rate. This capacity is divided among six time slots, two of which are assigned to each user in the current implementation, which uses a 7.95 Kbs vector sum excited linear prediction (VSELP) speech coder (13 Kbs with error protection). Thus each 30 KHz wide DTC can serve three users simultaneously and with the same reuse pattern. IS-54 provides triple capacity (number of user channels per cell) over AMPS. When half-rate coders are introduced, each 30 KHz frequency channel will be able to accommodate six user channels, giving another doubling of capacity. The addition of a Digital Traffic Channel (DTC) also provides capabilities for voice and data privacy [U.S. Army, 1995].

1. The Cell

The cell is the smallest unit of the cellular communication architecture. Cellular communication employs a terrestrial concept in which radio technology provides high capacity mobile portable communications. This enables mobile subscribers to link to the Public Switched Telephone Network (PSTN) via a system of small cells containing its own transmitter, receiver and antenna. Hence the name cellular communication.

The hexagon represents the base level of the communication architecture because of its convenience in showing interlocking, non-overlapping coverage. Cells typically range from two to twenty miles in diameter and represent the coverage area for a particular cell site. Ideally, a cell would be a perfect hexagonal shape, but due to geography, zoning regulations and RF propagation, that is not possible. Theoretically, the cell tower should be centrally located within a cell, but due to buildings, radio equipment, antennas and data terminals, the cell tower is

usually strategically located for best reception and transmission of signals as shown in Figure 9. Due to irregularity of the terrain, actual coverage areas preclude the ability to have a honeycomb for the overall configuration.

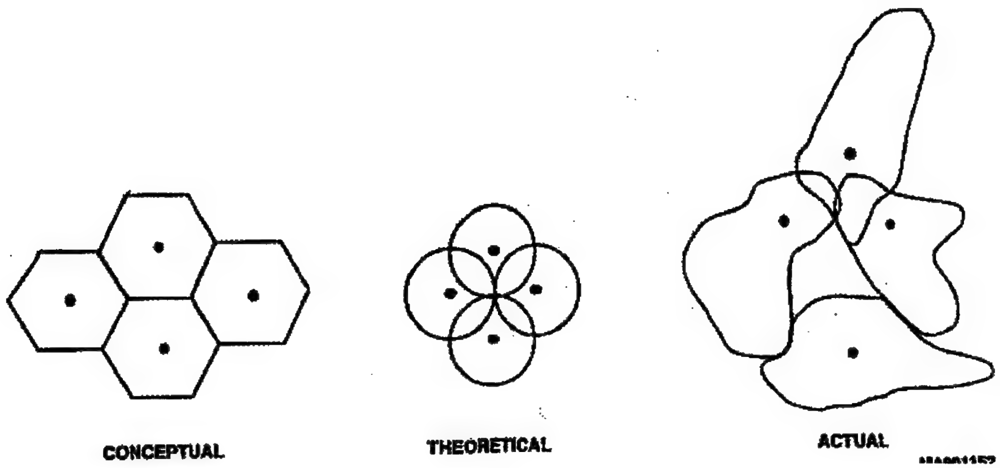

Figure 9. Cell Structure

Source: [AST, 1993, p. 15].

2. Call Handling

When the cellular phone is turned on, it constantly scans a set of assigned channels for that particular cell, subject to the restriction that adjacent cells cannot use the same channels. The assumption can be made when setting up a cellular system that each hexagon has only one cell site and the number of cells assigned to a given system depends on the RF propagation characteristics of the coverage area and the transmission quality objective for the system (Bucher, 1991, p. 22).

While an active cell phone is scanning available channels, it tries to find the strongest signal to await for incoming calls. If someone calls a cellular phone from the PSTN, the number is forwarded to the Mobile Telephone Switching Office (MTSO) which coordinates all switching functions. The subscriber is located by a paging function in which the MTSO transmits an identification number over the forward control channels (mobile to land). Once the cellular phone acknowledges, it will respond on a reverse control channel (land to mobile)

to the cell site which is known as a page reply.

When a cellular subscriber receives a call, the unit continuously transmits a data signal to let the MTSO know the unit's location. When the subscriber is transiting from one cell to another, the switch can track the signal so when a call comes in, the unit will ring alerting the user of an incoming call. See Figure 10.

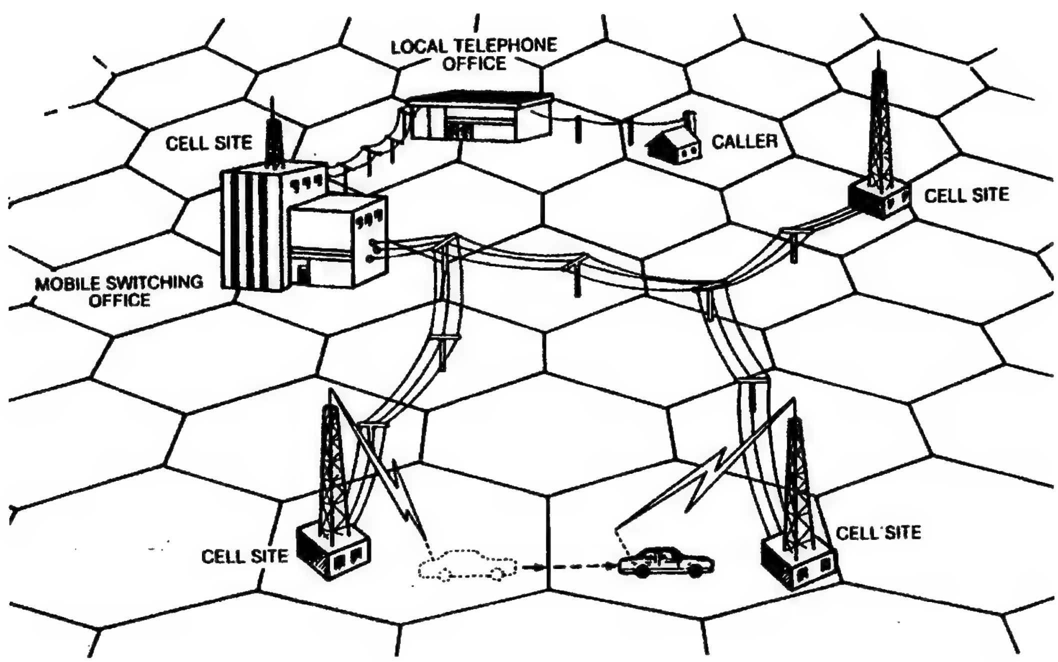

Figure 10. Placing a Cell Call

Source: [GTE Backgrounder, 1995].

3. Time Division Multiple Access

D-AMPS utilizes TDMA as its multiple access. In TDMA, several users utilize the same carrier frequency to communicate with the base frequency. TDMA is usually combined with frequency division multiple access (FDMA) so different frequencies are only reused in cells where the lack of distance would create interference. Many carrier frequencies are used in a cell, but each has its own TDMA bitstream and set of user terminals.

The TDMA used in IS-54 is very similar to GSM's TDMA in its principles and in using equally-tested technology. There are slight differences. For example, IS-54 uses a lower bit rate, narrower channel, and less interleaving, but the differences are not significant enough to consider them as different technologies [Analog Devices, 1996, p. 7].

C. ADVANTAGES AND DISADVANTAGES

1. Advantages

a. Compatibility

The North American standard is compatible with the existing AMPS standard, thus reducing the need to rebuild the cellular infrastructure in the United States. The multiple access technique used in the D-AMPS network has the ability to create a smooth transition from analog AMPS to the digital AMPS system and increase user capacity.

b. Security

Privacy and security has become one of the highest priorities among cellular users. In the past it was assumed, since the wireline telephone service was relatively secure, that cellular should be also. However, due to numerous breaches of security, there has been a campaign to prevent fraudulent use of the network. The IS-54B (version B), encrypts the mobile unit's Electronic Serial Number (ESN) prior to transmission. Each user has a stored A-key which is combined with the ESN to generate Secret Shared Data (SSD). CAVE is an encryption algorithm that uses a random number received from the base station to encrypt the ESN as shown in Figure 11 [Applied Signal Technology (AST), 1993, p. 62].

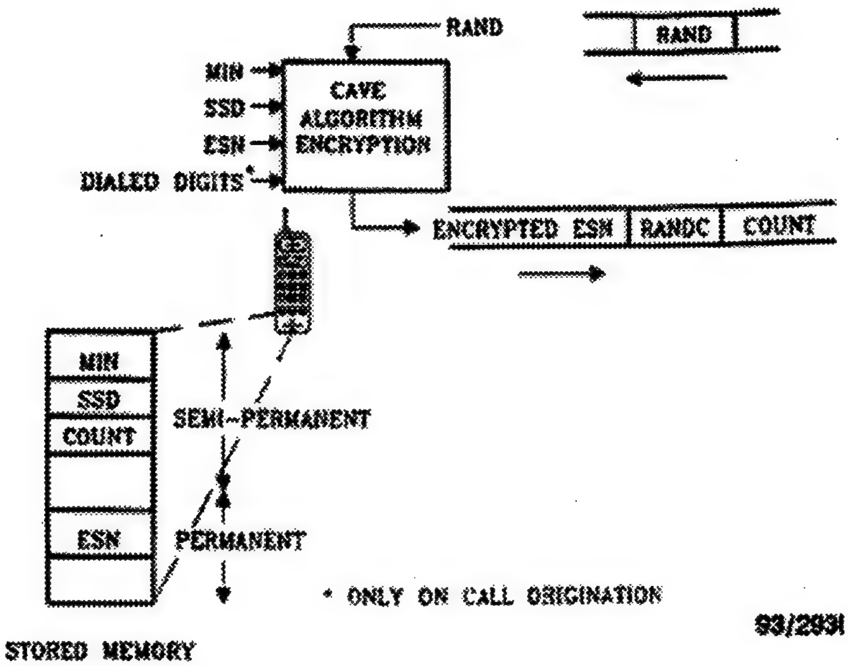

Figure 11. D-AMPS Security

Once on a digital traffic channel, a user may request a privacy mode if it is supported by the network. Digital speech data is encrypted when it is in the privacy mode and the SSD is used to generate a Voice Privacy Mask (VPM) using the CAVE algorithm. The VPM is then added (modulo-2) to the speech data [Applied Signal Technology (AST), 1993, p. 64].

c. *Digital Technology*

The digital technology of D-AMPS allows a higher capacity and increased performance through improved voice processing, bit-rate compression, interference rejection, better channel coding, and multiple access efficiency using digital multiplexing techniques. The digital technology is available commercially on the market and gives a capacity increase from 3.5 to 3.7 times the original AMPS [Sharrock, 1995 p. 8].

d. *TDMA*

D-AMPS uses a TDMA technique which is in actual operation today. TDMA has been established throughout the world and is operated

commercially in various standards. TDMA provides a smooth transition from AMPS to digital that will support a higher capacity. TDMA also accomplishes an efficient utilization of the existing infrastructure while still taking care of the existing AMPS subscriber [Sharrock, 1995, p.8].

2. Disadvantages

a. Spectrum Availability

One of the major problems with D-AMPS is the availability of the spectrum. The already existing AMPS network is congested and D-AMPS must operate within the same constraints of the spectrum. Networks like GSM and PDC operate in an unused part of the spectrum and have the opportunity to grow.

b. Capacity Problems

Problems with capacity came to the forefront approximately six years ago in major metropolitan areas like Chicago, New York, and Los Angeles. FM could not handle the demand and the Federal Communications Commission (FCC) would not allocate additional bandwidth for cellular. IS-54 was the solution to the capacity problem. However, the TDMA technique only increases the user capacity by three whereas standards like GSM and CDMA are reported to increase user capacity by eight and ten to twenty times more than AMPS, respectively [Sharrock, 1995, p. 2].

D. MARKETING OUTLOOK

As of early 1995, the analog AMPS and digital AMPS has been a huge success in the United States and in 75 additional countries as shown in Table 4. The AMPS system services more cellular users than any other system in the world. It is highly probable AMPS will survive past the year 2000.

Table 4. Current AMPS, D-AMPS Users

Angola	China	Jamaca	Singapore
Anguilla	Colombia	Kazakhstan	Sri Lanka
Antigua & Barbuda	Costa Rica	South Korea	St. Kitts & Nevis
Argentina	Cote D'Ivoire	Laos	St. Lucia
Aruba	Cuba	Lebanon	St. Martin/Bartholemy
Australia	Curacao	Madagascar	St. Vincent/Grenadines
Bahamas	Dominican Republic	Malaysia	Surinam
Bangladesh	Ecuador	Martinique	Taiwan
Babados	El Salvador	Mexico	Thailand
Belize	Gabon	Monterrat	Trinidad & Tobago
Bermuda	Georgia	Netherlands Antiles	Turkmenistan
Bolivia	Ghana	New Zealand	United States
Brazil	Grenada	Nicaragua	Uraguay
Brunei	Guadeloupe	Pakistan	Uzbekistan
Burma	Guam	Paraguay	Venezuela
Cambodia	Guatemala	Peru	Vietnam
Canada	Guyana	Philippines	Virgin Islands (British)
Cayman Islands	Hong Kong	Russia	Zaire
Chile	Israel	Samoa (American)	Zambia

Source: [US Army, 1995]

1. Positive Aspects

a. Market Acceptance

D-AMPS has been advantageous in spreading across the Americas and some of the Asian countries. The initial operation of TDMA became a reality in 1988 when its first field trials were conducted in October 1991 and the first systems became operational in 1992. For a system to be accepted by the market, it takes approximately five years of operational experience for a system to grow. This is where D-AMPS has an advantage over some of the newer technologies that have not even reached the market.

b. TDMA

In North America, seven tenths of the operators support TDMA. Operators from as far as South America and Asia have agreed that the D-AMPS network is the best and fastest way for carriers to introduce digital systems with

high functionality. By 1995 TDMA will have caught up with GSM, in terms of features and functionality, building on a ten-year-long experience base of satisfying user demands within the United States.

c. *System Integration*

For any digital standard to be successful, it must cater to the subscriber. There must be a way for the user to interface with the digital standard. As the TDMA market expands, the subscriber equipment must be able to keep up with the user demand and be dual-mode capable. Cellular equipment must be able to be upgraded to TDMA digital capability in cost effective increments. Cellular service providers can transition from analog to digital, one radio unit at a time, without having to start from the ground up.

d. *Transition from Analog to Digital*

TDMA is a smooth transition from analog AMPS to digital AMPS. It enables the use of the existing infrastructure and still caters to the analog subscribers. TDMA is very flexible. It allows for digital to be installed wherever there is a need to support the existing analog AMPS subscribers [Sharrock, 1996, p. 8].

2. Negative Aspects

a. *Growth*

In year 2000, it is predicted D-AMPS will occupy 44 percent of the cellular market in the world. Europe will not be one of the markets. Currently, there are no D-AMPS networks in Europe because the frequency bands are already assigned to UHF TV. D-AMPS has grown in a few countries outside the United States and has picked up new subscribers, but the problem with D-AMPS is, instead of the focus being on engineering and design, the focus is on marketing the advantages of digital cellular [U.S. Army, 1995].

b. GSM

GSM is making headway into the United States cellular market, and it is forecast that one third of the Personal Communication Services (PCS) will be GSM [Huber, 1995, p. 6]. GSM has become one of the leading standards worldwide, not only in Europe but also in Asia, Africa, Australia and the Middle East. GSM also has the ability to provide many services to the American customer such as affordable, easy-to-use, secure and compact communications, and in the near future, GSM will be expanding from 25 MHz bandwidth to 35 MHz bandwidth for increased user capacity.

c. Market

The United States is hindered by the need to maintain the AMPS system. There is an economic need for the new system to operate on the existing groundwork and a new digital standard would cause the AMPS infrastructure to become obsolete. Economically, this could be a costly enterprise in the United States. The cost of cellular service and equipment would have to rise to cover the cost of a new system. Ultimately, the United States, by maintaining the AMPS system, may possibly render its future system incompatible with other countries that are on a different standard.

IV. CODE DIVISION MULTIPLE ACCESS (CDMA)

A. BACKGROUND

In 1989, a committee of the Telecommunications Industry Association (TIA) adopted the first North American digital interim standard IS-54 in the United States. The system was to be based on TDMA as the common air interface (CAI) radio channel for all digital transmissions. Soon thereafter in 1990, the second interim standard appeared on the market developed by Qualcomm Inc. of San Diego, California. Qualcomm developed a chip set to implement the key reception and demodulation functions of a Code Division Multiple Access base station. The proposed system used a spread spectrum technique based on Code Division Multiple Access (CDMA). Originally designed for the military to prevent signals from being jammed or intercepted by hostile encounters, it was thought to be an inefficient use of the spectrum. However, spread-spectrum is a well-established technology that has only recently been applied in the digital cellular market.

Multiple conversations are spread across the whole cellular spectrum. Each telephone or data call in the same bandwidth is assigned a unique code. This allows a call to access the entire cellular bandwidth with minimal interference.

CDMA promises to provide the following enhanced services [Titan Corp., 1995, p. TECH-11]:

- Increased system capacity that will eliminate most busy signals, dropped calls and cross talk resulting from system overcrowding
- Caller identification
- Lighter portable phones with improved talk and standby time as a result of low power levels (1/25 to 1/1000 those of AMPS)
- Greater coverage both indoors and out

- Improved call quality in congested downtown locations and areas with hilly terrain that experience interference from reflected signals or "multipath" effect
- Enhanced privacy and elimination of cross-talk due to 4.4 trillion codes being made available to distinguish individual calls.

B. ANALYSIS OF THE SYSTEM

The IS-95 system uses a CDMA-based spread spectrum carrier with a 1.23 MHz spreading bandwidth for the core system. Each user's signal with CDMA consists of a different pseudorandom (PN) binary sequence also called direct sequence spread spectrum technique that modulates the carrier, spreading the spectrum of the waveform. Spread spectrum can simply be defined as a means of transmission in which the signal occupies a bandwidth in excess of the minimum necessary to send the information; the band spread is accomplished by means of a code which is independent of the data, and a synchronized reception with the code at the receiver is used for despreading and subsequent data recovery which uses a delay lock loop system to perform this function [Pickholtz, Schilling, Milstein, 1982, p. 855]. A large number of CDMA signals share the same frequency spectrum. If CDMA is viewed in either the frequency domain or the time domain, the multiple access signals appear to be on top of each other as shown in Figure 12. The signals are separated in the receivers by using a Rake receiver (explained below) that accepts only signal energy from the selected multipath of the binary sequence and despreads its spectrum. The other users' signals, whose sequences do not match, are not despread in bandwidth and, as a result, contribute to the noise only and represent a self-interference generated by the system [Newson, Heath, 1994, p. 84].

The CDMA system is suited to take full advantage of the frequency reuse ability of the pseudorandom binary sequences. Each cell can be on the same wideband frequency channel and separated by a different sequence. This property

allows any pseudorandom binary sequence, unlike the FDMA approach in which neighboring cells must not use the same channels [Kerr, 1992, p. 36].

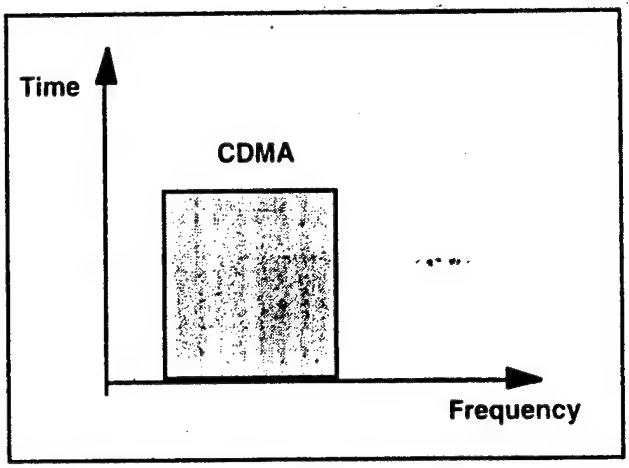

Figure 12. Code Division Multiple Access

Source: [Garg, Wilkes, 1996, p. 42]

1. Rake Receiver

A Rake receiver is distinctive to the CDMA system. It has the ability to add spatial diversity and accomplish the soft-handoff function. When a mobile station is at the edge of a cell, it begins to lose RF. The MTSO will sense this and assign the mobile another PN sequence with the same carrier frequency. At this point, the original MTSO and the receiving MTSO both transmit the same spreading sequence on the same channel. The rake receiver allows the rays from the receiving MTSO to be optimally combined.

2. Spread Spectrum

The spread spectrum approach uses a signal spread across a given bandwidth that is much wider than the information to be transmitted. It is then modulated with a waveform that has nothing to do with the signal, thus making it difficult to detect. Spread spectrum can be broken down into two main techniques: direct sequence spread spectrum and frequency hopping.

a. Direct Sequence Spread Spectrum (DSSS)

Direct sequence is achieved by spreading the spectrum and modulating the original signal with a wideband signal relative to the data bandwidth. The end result is a mixed signal that sounds like noise. This signal is transmitted to a receiver that has the ability to decode the noise and leave only the original signal.

b. Frequency Hopping (FH)

Frequency hopping randomizes the sequence in which a transmitted signal occurs by hopping across the spectrum. If the signal is truly random, it is very difficult for the jammer to predict the location of where the next "hop" will be. FH can occur anywhere in the allocated bandwidth, and the end result is a reduction in the interference of nearby users.

3. Frequency Reuse

CDMA does not require a reuse pattern like TDMA as shown in Figure 13. Subscribers in every cell can use the same frequency at the same time. The discriminating factor between subscribers is the unique code assigned.

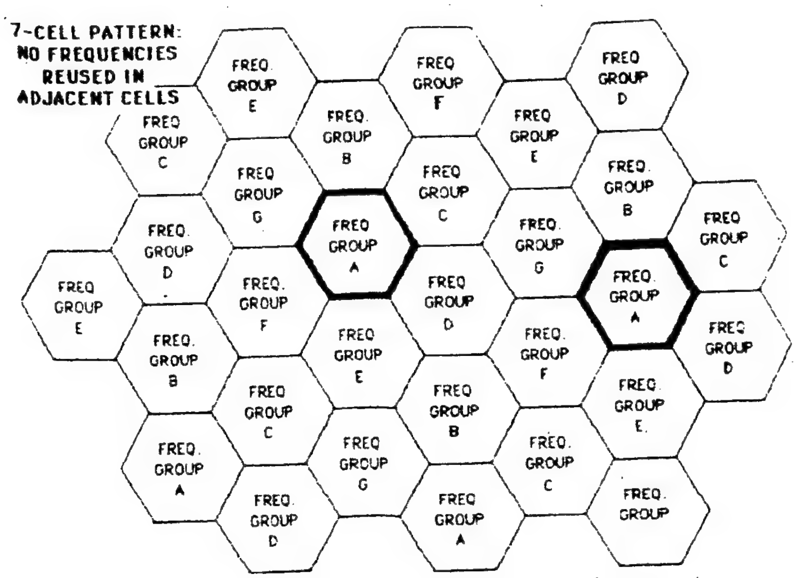

Figure 13. Frequency Reuse in TDMA

Source: [Calhoun, 1988, p. 42].

Frequency reuse is a concept used in cellular communications which states that by reducing the coverage area and increasing the number of small cells, the same frequency can be reused in different cells. Through early calculations it was determined that interference would occur between mobile cellular phones if the same frequencies were reused in adjacent cells. A reuse pattern of seven is the common scheme for cellular systems. In CDMA, only one frequency pattern is needed, so only one reuse pattern is needed as illustrated by the "A" in the CDMA frequency reuse pattern as shown in Figure 14.

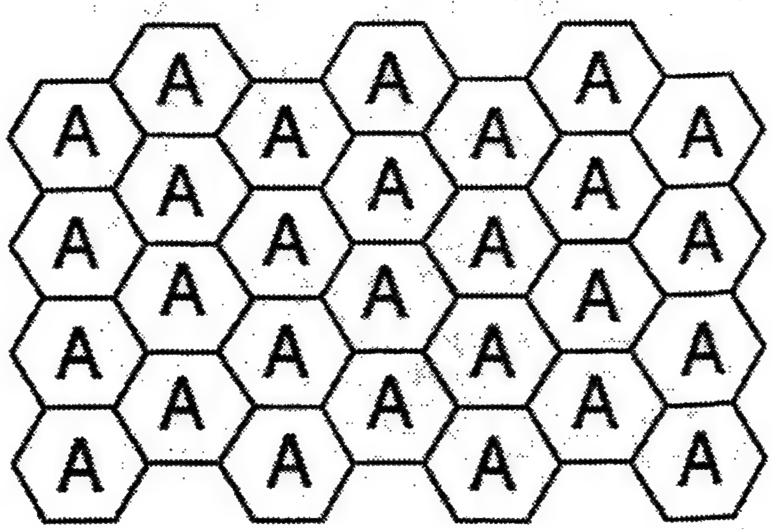

Figure 14. CDMA Frequency Reuse

Source: [Digital by Qualcomm, 1996, p. 20].

The current cellular transmission system uses a Frequency Division Multiple Access (FDMA) with an FM waveform. The FDMA uses the spectrum from 869 to 894 MHz. Each channel or call uses a unique 30 KHz frequency allocation. The cells must be spaced far enough apart that a reused frequency does not interfere with an adjoining cell. This limitation reduces the available capacity in any one cell and places major constraints on the cellular system design. The IS-

95 CDMA system has a frequency reuse close to one. The forward link transmits another time offset version of a binary sequence in each cell site. Almost any sequence can be placed next to another sequence. Since a simpler frequency reuse is utilized, a cell site can be divided into smaller sectors. Just one cell sector can be divided into three sectors of 120°, thereby forming three independent cell sites. The capacity of each cell is increased by a factor of three. Practical limitations of isolation and cost would limit most applications to at most six sectors in present cellular systems. The practical reuse is in a location that has a call "hot-spot," such as a major freeway intersection or blocked roadway. In this situation, a temporary cell site can be set up and immediately integrated with all the cells in that sector without a major change in system frequency planning [Zehavi, Tiedemann, 1994, p. 85].

4. Soft-Handoff

A soft-handoff is the function of CDMA that allows a call to be temporarily serviced as it is "handed" from one cell to another. This process prevents calls from being dropped and reduces the ability for the user to detect the transfer. After a call is initiated, the mobile station continuously scans adjacent cells to determine if the cell has exceeded its signal threshold. The mobile station will indicate this by sending a message that contains the identity of the new cell and its signal strength. The base station will now begin to initiate a soft handoff. When the signal strength of the old cell begins to decrease below a designated threshold, the mobile station will report the identity of the old cell and its new signal strength. The base station can now terminate the soft handoff. When a mobile station is transiting between two cell sites, the call is supported by communication between two cell sites. The original cell site only discontinues handling the call when the mobile station is firmly established in the new cell [Newson, Heath, 1994, pp. 673-684].

5. Base Station Chip Set

The Base Station Chip Set was made available to CDMA licenses and its three basic components consist of the Base Station Demodulator (BSD), the Base Station Modulator (BSM), and the Serial Viterbi Decoder (SVD). In a channel element there are four BSDs with four demodulation paths for the reverse link., one BSM which performs the forward link, and an SVD which handles the decoding operation [Titan Corp., 1995, pp. TECH 11-14].

a. *Base Station Demodulator (BSD)*

The Base Station Modulator is the component that receives and processes the reverse link in the CDMA signal. Each BSD consists of a demodulator and two searchers. A searcher is similar to a finger, but it is not equipped with a time-tracking loop. Both can select input from multiple sources. The demodulator, also known as a finger, is also a single path receiver that decimates, despreads, and demodulates the incoming data streams [Titan Corp., 1995, pp. TECH 11-14].

b. *Base Station Modulator (BSM)*

Two functions are performed by the BSM and they are CDMA forward link modulation and the de-interleaving for the reverse link. The BSM performs forward link modulation and can be configured in four different channel modes on the link. On the reverse link, the BSM interleaves the demodulated signal stream provided by the channel element processor. This de-interleaved signal is serialized and sent to the SVD [Titan Corp., 1995, pp. TECH 11-14].

c. *Serial Viterbi Decoder (SVD)*

The Serial Viterbi Decoder (SVD) applies the Viterbi algorithm to decode a synchronized and quantized symbol stream. The SVD includes an input buffer that allows data to be received via a serial input. The SVD can be configured to support two reverse link channel modes (access and traffic) and

receives a 576-symbol buffer every 20ms for decoding at full data rate [Titan Corp., 1995, pp. TECH 11-14].

6. CDMA Mobile Station Modem

Qualcomm Incorporated also developed a Mobile Station Modem (MSM) Application Specific Integrated Circuit (ASIC) to implement the CDMA specific portions for a dual-mode (CDMA-AMPS) subscriber unit. The MSM integrates three modules into a single custom ASIC, and it consists of the Subscriber Demodulator, Subscriber Modulator, and Serial Viterbi Decoder modules [Titan Corp., 1995, pp. TECH 11-14].

a. Subscriber Demodulator Module

The Subscriber Demodulator Module receives and processes the incoming baseband CDMA forward link signal (base station to subscriber unit) into information symbols that are de-interleaved in the Subscriber Modulator Module [Titan Corp., 1995, pp. TECH 11-14].

b. Subscriber Modulator Module

The Subscriber Modulator Module performs two functions. First it modulates the reverse link (subscriber unit to base station), and second it de-interleaves the forward traffic channel by taking the demodulated symbol stream from the Subscriber Demodulator Module and de-interleaves this stream prior to processing by the Serial Viterbi Decoder Module [Titan Corp., 1995, pp. TECH 11-14].

C. ADVANTAGES AND DISADVANTAGES

1. Advantages

a. Spread Spectrum Technology

Spread spectrum is transparent to the user and it is very difficult to determine if it is actually being used. Users will experience little interference

between calls unlike some of the other digital access techniques on the market like D-AMPS.

b. Capacity

CDMA claims to have capacity improvements of ten to twenty times that of analog systems. It would be able to relieve the congestion in some of the more crowded metropolitan areas.

c. Third Generation System

CDMA promises to be the future technology candidate for the up and coming third generation satellite systems. Since CDMA has the ability to produce a higher data rate, this will enable it to deliver the data rates needed for satellite communications.

d. Sound Quality

The make-before-break technique (ensures that the mobile station has made a solid transition from one cell to another before releasing from the weaker signal) allows for a seamless transition throughout the network and offers continuous data transmission which is practically invisible to the user. The end result is fewer dropped calls.

e. Interoperability

Some of the CDMA systems like IS-95 were designed to be compatible with the existing analog networks. A system like GSM will fall to the disadvantage because it is not compatible with North American cellular. Many of the protocols in GSM would make it difficult to operate in the United States.

f. Flexibility

CDMA requires 80 percent fewer base stations which directly reduces the cost of infrastructure equipment, real estate, site improvement, spectrum backhaul, and maintenance when compared to GSM [Motorola, 1996, p. 95].

g. Cell reuse

Cell reuse reduces the need to have frequency planning. It helps control operating expenses because there are no guard bands as in TDMA, but this does not totally eliminate the need for frequency management.

2. Disadvantages

a. Time Scale

CDMA is behind on its proposed entry date into the market. Commercial service was supposed to begin in 1994, and it was delayed. Due to the uncertainty of the new technique, many major companies chose to take a wait-and-see attitude to see how well the system would perform before giving a solid commitment.

b. Performance

There is still a question as to actually how well CDMA performs. CDMA is still under testing and has not been fully implemented on any market. Many companies are starting to commit, but some still are using the wait-and-see attitude here also.

c. Quality

CDMA further proposes to be the only technique that offers features like soft-handoff, diversity against fading, and power control, but these features exist in other techniques like TDMA.

d. Capacity

CDMA proponents stand strongly behind the claim that it can operate at ten to twenty times the capacity of AMPS. However, Ericsson has performed calculations and the results indicate that CDMA will only deliver 4-5 times that of AMPS [Sharrock, 1996, p. 5].

D. MARKETING OUTLOOK

It is difficult to predict the actual future of CDMA on the market, but it is the most promising of the digital techniques. Apparently, tests have gone well, but many question when the technology will actually hit the market. Even though it is not actually on the market, industry appears to be supporting it. Listed below are some of the companies that are supporting CDMA:

- Qualcomm
- AT&T
- Motorola
- ALPS
- GSIC
- Samsung
- Sony
- US West
- Sprint
- Bell Atlantic
- Time Warner

Field demonstrations have been conducted as early as 1989 and continue. To date, Qualcomm has successfully completed more than forty technical trials on five continents. In some of the actual field trials, CDMA's fundamental features of high capacity, superior voice quality, low power operation, multipath reception and soft handoff continue to be successfully demonstrated under a variety of conditions. CDMA's potential has become known throughout the industry and many key service providers and manufacturers, some of whom had already devoted considerable resources to developing TDMA, have chosen to sign agreements with Qualcomm in support of CDMA technology validation activities [Motorola, 1996, p. 5].

CDMA has hit the international market in the Far East along with a wide variety of other cellular standards, including AMPS, GSM, and various forms of TACS, PDC, and DCS 1800. Just like the rest of the world, the spectrum is becoming crowded and governments are forcing the mobile providers to digital

standards. In Taiwan and Hong Kong, the governments want all cellular networks to be digital by 1997. Japan will start restricting the number of analog subscribers in 1996. In South Korea, the analog system is saturated and only about 70 percent of the calls can be completed [Titan Corp., 1995, p. FE-2]. CDMA will be relatively easy to integrate into the Far East market because it shares a common network with systems like AMPS, and a dual-mode phone can alleviate the need to invest in a total revamping of the existing network.

V. PERSONAL DIGITAL CELLULAR (PDC)

A. BACKGROUND

Analog cellular communications in Japan was introduced in 1979 approximately seven years before the United States. The first cellular company in 1979 to arrive on the market was Nippon Telegraph & Telephone (NTT). NTT was owned by the government and had total market control until 1985 when Japan established the Telecommunications Business Law, which privatized NTT and ended legal monopolies. The two companies that maintained a major monopoly in the Japanese cellular market were: NTT, the public telephone corporation, and the Kokusai Denshin Denwa (KDD). In 1986, the Ministry of Post and Telecommunications (MPT), the governing agency of the cellular market, licensed two additional service providers, Nippon Ido Tsushin and Daini Denden Inc. (DDI), to compete with NTT, but neither of the companies ever received a national license to compete with NTT on a large scale. Nippon Ido was only licensed to provide service to the Tokyo-Nagoya area. DDI operated in mostly residential and suburban areas.

The Personal Digital Cellular (PDC), also known as the Japanese Digital Standard (JDC), was Japan's digital mobile communication system solution whose specifications were defined by Japan's Research and Development Center for Radio Systems (RCR). It is a TDMA-based system that operates in the 800 MHz and 1.5 GHz radio frequency bands, and therefore is similar to the American TDMA network with the only exception being it was not designed to operate in the dual mode [Schneiderman, 1994, p. 108].

The PDC was developed to allow Japanese cellular users a way to maintain continuous communications while roaming in areas of Japan where different cellular providers control various areas of the Japanese countryside. The system

also provides a more efficient use of the frequency spectrum, implementation of digital signal processing to improve speech and data quality, and the possibility for encryption for security [U.S. Army, 1995, p. GSM-1].

PDC has not been defined as a standard as well as GSM. The only aspects defined were the air interface to the mobile phones, and the interface from the mobile network to public network. Its design was left open to allow a greater freedom for the different suppliers to propose their own solutions. Presently, PDC has only been implemented in Japan.

One of the major suppliers for PDC is Ericsson through a joint venture with Toshiba. Currently, they have 37 percent of the PDC market in terms of the number of subscribers served [Titan Corp., 1995, p. TECH-16].

B. ANALYSIS OF THE SYSTEM

The Cellular Mobile System 30 (CMS 30) is the PDC network designed by Ericsson that will be used as the example in this analysis of the system. The network is composed of three main elements: the Mobile Switching Center (MSC), the Home Location Register (HLR), and the radio base stations (BS).

1. AXE Switching Center

The MSC and HLR functions in PDC are similar to the functions described in Chapter II GSM. In the PDC network, the platform used for switching in digital telephone switches and for wired and mobile networks is known as Automatic Cross-Connection Equipment (AXE) technology. AXE is housed in the MSC and HLR and in the interface for the Base Station. AXE is the technology used in CMS 30 that introduces a new concept called transit switches which assist in the connection between the mobile network and the public network. In a city with a large customer base of cellular users, the mobile network and the public network can be made with just two transit nodes instead of many MSCs. The second transit node is only for redundancy.

2. Radio Base Station

The base station in the CMS 30 consists of two different station models: the RBS 300 and the RBS 310. Both systems are designed to be used in the 1500 MHz PDC network.

The RBS 300 was designed for high-capacity cell sites, which can be built up in three stages to serve three radio cells, with up to 20 transceivers (60 voice channels) per cell. The smaller unit, the RBS 310 was designed for outdoor use and is delivered pre-configured and tested in a weather-proof cabinet. The RBS 310 can serve one or two cells with up to eight transceivers (24 voice channels) [Titan Corp., 1995, p. TECH-17].

3. PDC Standard

The PDC system's basic design consist of TDMA as the multiple access method with three time slots. That number will increase to six once a half-rate CODEC has been developed.

Modulation is $\pi/4$ shifted QPSK for the following reasons:

- Efficient spectrum utilization
- Ease of linear power amplification
- Detection ease

The TDMA frame structure was designed in consideration of spectrum efficiency, transmission quality and efficient call control. The guard time is inserted between TDMA bursts. In order to suppress the interference between bursts caused by the up and down ramp burst amplitudes, an additional period, ramp time, is reserved. A synchronization/training word is placed in the middle of each burst [Kuramoto, 1992, p. 2].

4. Call Handling

a. Location Registration

In PDC, location tracking is handled by the Mobile Station (MS). As long as the system is aware of the location of the MS it is able to handle network management more efficiently and reduce the connect time of a call.

The MS will inform the network about its location at all times and will update the system. Once the location is authenticated, the HLR will be updated with the current information of the subscriber.

b. Call to Mobile Subscriber

This function is activated when a call is received in the MSC designated by the mobile subscriber number analysis in the calling network. The first step is taken by the MSC to interrogate the HLR for information about the called mobile subscriber. The servicing MSC receives the call and pages the mobile station until it responds to the page. Then authentication will be performed. If it is successful, the MS will answer the call and once acknowledged, the call will proceed until terminated [Ericsson, 1995, p. 15].

c. Call from Mobile Subscriber

This function is activated when the serving MSC receives a request to establish a call from a mobile station. Since the MS has been previously registered, once the call is authenticated the servicing MSC will already have the information needed to setup the call. The MSC will assign a traffic channel to the MS, and the call will be routed to the subscriber.

d. Locating and Handover

A MS is constantly moving from one place to another during a conversation, therefore calls may have to switch from one cell to another without a disconnect. The process of transferring a call from one channel to another in a different cell is known as a handover. In the CMS 30 system, it is a completely

autonomous system that involves a process of collecting and evaluating measurements from the mobile station to the base station. The end result would be better sound quality.

C. ADVANTAGES OR DISADVANTAGES

1. Advantages

In the early 1990s deregulation and competition in Japan has caused an opening up of the cellular market and terminal market for other providers in the newly allocated spectrum. With so many digital networks currently on line, the Japanese market has experienced a phenomenal growth rate. To date there are a total of eight million cellular subscribers in Japan and three million are PDC subscribers [Ericsson, 1996, p. 1].

2. Disadvantages

PDC has only been implemented in the Japan, and may possibly spread to other countries in South East Asia in the near future, but it may not venture past the Far East market. GSM dominates the European market and D-AMPs dominates the North American market.

PDC is not a dual-mode system. It was designed to operate only in the digital mode. This would make it difficult to be implemented in the North American market where AMPS prevails as the analog system.

D. MARKET OUTLOOK

Wireless communications have experienced a phenomenal growth rate over the past two years in Japan. The Ministry of Post and Telecommunications predicts the number of cellular users to exceed 32 million by the year 2010 [Titan Corp., 1995, p. FE-19].

The Far East has adopted many cellular standards to include AMPS, GSM, and various forms of TACS, PDC, and DCS 1800. Just like the rest of the world,

the frequency spectrum for cellular is starting to reach the saturation point, and many Far East governments such as in Hong Kong and Taiwan are pushing cellular providers to explore the digital option. Japan has begun restricting the number of analog users, and Hong Kong and Taiwan want all their networks to be digital by 1997. Already, in South Korea, due to saturation, 30 percent of the calls placed cannot be completed [Titan Corp., 1995, p. FE-2].

Analysts predict digital subscriptions will exceed analog by the end of 1997. GSM, CDMA, and the Japanese PDC systems are expected to comprise 68 percent of the market by the year 2000 [Titan Corp., 1995, p. FE-2]. Korea and Taiwan will reach the 8-14 percent level and China is expected to have 2 percent density by the same time [Titan Corp., 1995, FE-2].

VI. THE EVOLUTION TO A FUTURE DIGITAL CELLULAR STANDARD

A. SUMMARY

Digital cellular has grown beyond all expectations over the past decade and continues to exceed the most optimistic of forecasts. Cellular markets are developing all over the world, and digital cellular is surpassing analog cellular as the superior communication technique by alleviating the overcrowding and poor reception that has plagued analog for so long.

Society has evolved into a mobile community, and its communication needs are constantly changing, not only in the business arena but in the personal arena as well. Telecommunications has evolved so significantly this decade that cellular communication occupies a principal piece of the industry, and the need for high quality and high capacity communications is a must.

The emergence of digital cellular introduces the idea of market competition among the four major digital standards. The main decision-makers as to which standard will be the most widespread are the service providers; however, it is important to realize the customer has an even larger say in the decision process. Customers may have more impact on the standard than they realize. The choice of the standard is the decision of the service providers that provide the service to the customer. The customers in turn decide which digital standard they prefer by supporting a specific service provider.

The consensus of the market appears to be that one standard will not prevail, and there may be several. All the standards on the market will have a place in the near future of communications because in one way or another they have already been committed. This commitment will allow standards such as D-AMPS and PDC to remain alive on the market, but not necessarily as market

leaders due to their incompatibilities with other standards on the international marketplace. The standards that remain market leaders will have the greatest probability of being implemented into a leading international third generation system.

Upon review of the material available on the four major standards currently on the market, it would be very difficult for service demanders to endorse only one standard. The choice of a standard is based on the standard or standards that would provide the technology customers want, the timeliness to the market, and system viability to name only a few criteria. Standard selection is driven by the market. Once on the market, the marketplace will make the decision to move in the direction of a particular technology. All standards, regardless of whether they become the international standard, will have a niche in the market because of the backing and support of the company that initially has committed to them. Each standard brings with it numerous advantages and disadvantages. It is the responsibility of the market to sort it out and move toward the standard (or standards) that offers the most advantages. Until this can happen, there will always be a proliferation of standards and difficulty in migrating toward a universal system. Two of the standards appear to have a greater chance of becoming the next-generation market leaders. These are reviewed next.

1. GSM

a. Worldwide Success

GSM's success has spread beyond Europe and has operational networks worldwide such as in South Africa, Hong Kong, China, Singapore, Australia and New Zealand. Its worldwide success can also be attributed to its open architecture and evolving technology that was discussed in Chapter II. GSM's open architecture allows a more creative competition in the marketplace and stimulates growth. The evolving technology of its open architecture enables it

to migrate from a voice-only system to a system that offers a wide variety of services of not only voice but data as well.

b. Third Generation Systems

GSM is a very sound choice for the foundation of the new global satellite system. Many of its standards have been implemented to support a third generation system known as the Future Public Land Mobile Telecommunications System (FPLMTS) and the Universal Mobile Telecommunications System (UMTS) which is Europe's version of the FPLMTS.

GSM's successor will be able to integrate many of the existing services that are incompatible into an integrated system of radio and network infrastructure that can offer a wide range of services such as [Pandya, 1995, p. 49]:

- Digital system using 1.8 - 2.2 GHz band
  Multiple radio environments (cellular, cordless, satellites, and fixed wireless).
- Multimode terminals to provide roaming capability.
- Wide range of telecommunication services.
- High quality and integrity - comparable to fixed networks.
- International roaming and inter-system handover capability.
- Use of intelligent network capabilities for mobility management and network control.
- High levels of security and privacy.
- Flexible and open network architecture.

c. Reliable Communications

GSM has proven itself a reliable digital choice. It has spread to over 70 countries since 1992 and continues to spread into the Asian nations. GSM has twice the capacity of analog, and it has fewer dropped calls and interrupts. The system brings a higher level of audio quality, privacy, and link integrity between calls and the switched network [Johansson, 1995, p. 165].

d. Growth Potential

GSM has the capability to offer a variety of value-added services such as superior speech quality, service costs, mobile station costs, high-level security, international roaming, support of low-power hand-portable terminals and a wide variety of new services and network facilities [Redl, Weber, 1996, p. 23].

The GSM wireless standard, in the four years since its introduction, has become the world's most widely deployed digital cellular technology. Globally, there are almost 12 million GSM subscribers and over 30,000 new subscribers are signing up daily. By the end of the century there will be 230 networks in over 100 countries, and the total number of GSM subscribers will exceed 100 million [Ericsson, 1996, p. 3].

2. CDMA

a. Call Quality

CDMA's coverage area is larger than any other digital standard and the call quality is by far superior. With its new technology, there has been a vast improvement in call handling. There are marked improvements in the sound quality of the calls placed as the subscriber moves from one cell to another. The soft-handoff as mentioned in Chapter IV allows the caller to maintain a constant connection that goes unnoticed to the user as the call is being handed off to another cell.

b. Leading Edge of Technology

CDMA is the forefront of technology in digital cellular standards. It will be able to provide a superior solution for the wide spectrum of cellular communications like state-of-the-art solutions for cordless phones, office phones, wireless loops and Personal Communication Services (PCS).

CDMA technology uses a simple radio frequency planning component. This drives the cost per user lower than that of analog. The

combination of simpler RF elements and greater cell coverage means system planning is less of a challenge than with other techniques.

c. *Accessibility into the U.S. market*

CDMA has a better advantage of moving into the U.S. market and preventing the Europeans from taking a stronghold with GSM. CDMA was developed in the United States by Qualcomm Inc. and has a better chance of moving into that market because it is backward compatibility with AMPS.

d. *Open Architecture*

CDMA also has an open architecture like GSM that allows the network operators to have the utmost flexibility in obtaining the best cost/performance mix for switches, RF infrastructure, network equipment options and new network features [Johansson, 1995, p. 166]. Open architectures also make it possible for advanced and wireless systems to get into the market quicker.

B. CONCLUSIONS

GSM and CDMA are two unique techniques with the ability to be the next generation digital cellular standard. GSM is the more established technology of the two with a customer base that is growing by leaps and bounds across Europe and Asia. CDMA is the newest technology and has the potential to be a market contender once it has gone commercial.

Even though each digital technology boasts different advantages, they are not so different that one is any better than the other. There are basically different ways of approaching the complexity of digital communications and integration of systems. The final choice is up to the service demanders to determine which system will meet most of the needs of the network today and tomorrow.

C. AREAS OF FURTHER STUDY

1. Mobile Satellite Systems (MSS)

The vision of having the ability to communicate anywhere, anytime, and anyplace is slowly becoming a reality. The next step toward that vision is the third generation system known as Mobile Satellite Services (MSS). It is expected that millions of subscribers will be offered satellite personal communications by the year 2000.

MSS represents the ability to maximize mobility of users by providing global roaming and coverage to remote areas where terrestrial services may not be available. Global does not just mean the user can move around anywhere, but the communication system itself can move to another area to serve fixed or stationary users where the communication infrastructure is not quite developed [Titan Corp., 1995, p. 3].

2. Personal Communication Services (PCS)

PCS is defined as a set of capabilities that allows some combination of terminal mobility, personal mobility, and service profile management. It sometimes is used as an umbrella term that includes various wireless access and personal mobility services, but with a heavy emphasis on wireless access services using the spectrum around 1900 MHz [Pandya, 1995, p. 47].

PCS is envisioned as the next step in the migration of digital cellular communications. The services provided by PCS will allow people to communicate anywhere, anytime and anyplace in any form. PCS may well be the solution for global roaming and a way to access new markets in the future.

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